Proliferation Resistance and Safeguards by Design – The Safeguardability Assessment Tool provided by the INPRO Collaborative Project "PROSA" (Proliferation Resistance and Safeguardability Assessment)

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Abstract. Since the INPRO Collaborative Project on Proliferation Resistance and Safeguardability Assessment Tools (PROSA) was launched in 2011, Member State experts have worked with the INPRO Section and the Safeguards Concepts and Planning Division of the IAEA to develop a revised methodology for self-assessment of sustainability in the area of proliferation resistance of a nuclear energy system (NES). With the common understanding that there is "no proliferation resistance without safeguards" the revised approach emphasizes the evaluation of a new "User Requirement" for "safeguardability" that combines metrics of effective and efficient implementation of IAEA Safeguards including "Safeguards-by-Design" principles. The assessment with safeguardability as the key issue has been devised as a linear process evaluating the NES against a "Basic Principle" in the area of proliferation resistance, answering fundamental questions related to safeguards: 1) *Do a State's legal commitments, policies and practices provide credible assurance of the exclusively peaceful use of the NES, including a legal basis for verification activities by the IAEA?* 2) *Does design and operation of the NES facilitate the effective and efficient implementation of IAEA safeguards?* To answer those questions, a questionnaire approach has been developed that clearly identifies gaps and weaknesses. Gaps include prospects for improvements and needs for research and development. In this context, the PROSA approach assesses the safeguardability of a NES using a layered "Evaluation Questionnaire" that defines Evaluation Parameters (EP), EP-related questions, and Illustrative Tests and Screening Questions to present and structure the evidence of findings. An integral part of the assessment process is Safeguards-by-Design, the identification of potential diversion, misuse and concealment strategies (coarse diversion path analysis), and the identification of safeguards tools and measures to meet facility or activity specific safeguards objectives. The usefulness of this approach has been preliminarily tested and demonstrated in a case study performed by KAERI.

1. INTRODUCTION

The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was established in 2000 – as an IAEA flagship project, through a General Conference resolution – to help ensure that nuclear energy is available to contribute to meeting the energy needs of the 21st century in a sustainable manner. INPRO's activities are centered on the key concepts of global nuclear energy sustainability and the development of long-range nuclear energy strategies, so that nuclear energy is and remains available to meet national energy needs. Within the INPRO concept of sustainability, *Proliferation Resistance* (PR) is one of the INPRO subject areas [1] evaluated in a nuclear energy system assessment (NESA).

The INPRO sustainability assessment methodology in the area of proliferation resistance has evolved over the years, with the INPRO Collaborative Project (CP) *Proliferation Resistance: Acquisition/Diversion Pathway Analysis* (PRADA) [3], which was completed in 2010, representing an important milestone. A main conclusion of that CP was that the robustness of barriers to proliferation is not a function of the number of barriers or of their individual characteristics but is an integrated function of these and can be measured by determining whether the safeguards goals can be met. Consequently, key issues in the proliferation resistance assessment process became the State's legal framework that enables the IAEA to achieve its safeguards objectives, and "*safeguardability*" that can be described as a property of a nuclear system, based on design features and operational modalities, that facilitate effective and efficient safeguards implementation.

2. RESISTANCE BASIC PRINCIPLE, USER REQUIREMENTS, AND CRITERIA IN THE AREA OF PROLIFERATION

The proliferation resistance sustainability assessment process proposed by PROSA follows the same structure as the INPRO Methodology with one Basic Principle (BP), three supporting User Requirements (UR), and corresponding Criteria (CR) with Indicators (IN), Acceptance Limits (AL), and Evaluation Parameters (EP).

In line with IAEA-STR-332 [4], which defines proliferation resistance as: *"that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by States in order to acquire nuclear weapons or other explosive devices",* the BP remains essentially unchanged from IAEA-TECDOC-1575 [2]: "*Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for [nuclear energy systems] to help ensure that [NESs] will continue to be an unattractive means to acquire fissile material for a nuclear weapons program. Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself".* Since no proliferation-proof NES is possible so long as special fissionable material (SFM) is involved in significant quantities (SQs), extrinsic proliferation resistance measures – various institutional controls and verification measures – will remain essential, even in case of an increased level of effectiveness of intrinsic features.

Intrinsic design features that may affect barriers against proliferation, such as low levels of uranium enrichment or a lack of isotope or chemical separation technologies within the NES, cannot independently address the objective of preventing proliferation. At a minimum, transparent verification of materials, facilities and activities is the only certain approach to create assurance of peaceful use. Effective and efficient implementation of IAEA Safeguards will remain an essential part of proliferation resistance and a legal requirement for the operation of a NES in Non-Nuclear Weapon States (NNWS) under the Non-Proliferation Treaty (NPT) [5] and a Comprehensive Safeguards Agreement (CSA) [6]. Ultimately, the robustness of barriers against proliferation, built by intrinsic features and extrinsic measures, is determined by the possibility for the IAEA to achieve its safeguards objectives [3].

3. The PROSA Proliferation Resistance Assessment Process

The PROSA PR assessment process is intended for NESA self-assessments performed by national subject matter experts, and potentially on assessments by designers/vendors of a NES facility or activity. The assessment has been devised as a linear process, evaluating the NES against the "Basic Principle" in the area of proliferation resistance, which ultimately leads to the conclusion that the *"NES is or is not in agreement with the INPRO Basic Principle in the area of proliferation resistance"* [8]. Even so, the primary value of the assessment is not the top level conclusion, but rather, to gain an appreciation of where gaps exist at Criteria and Evaluation Parameter level, thereby suggesting directions to pursue to improve long term sustainability of the NES. PROSA replaces a previous approach of "ranking" PR using semi-quantitative evaluation scales, from "*very weak*" to "*very strong*", in favour of a questionnaire approach to clearly identify gaps and weaknesses. Gaps include prospects for improvement and needs for research and development.

Questions considered in the assessment process include:

- *Does the NES provide unirradiated direct use material (by diversion or misuse) that can be used for a nuclear weapon?*
- *Do the State's commitments, obligations and policies allow the IAEA to provide credible assurance of the exclusively peaceful use of the nuclear energy system (NES)?*
- *Does design and operation of the NES facilitate the implementation of IAEA safeguards?*
- *Can all plausible acquisition paths be covered by intrinsic features compatible with other design requirements, and extrinsic measures that are suitable to reduce the attractiveness for a proliferator to use these acquisition paths?*

The first Question is part of "NES PR Information Catalogue" compiled by the assessor regarding the nuclear material, facilities and technologies in the NES.

The second question is associated with UR1, assessment of the State's commitments, obligations and policies regarding non-proliferation. The assessor is asked to respond to a list of questions that evaluate whether the State's legal commitments, obligations and policies are sufficient on the whole to provide a basis for credible assurance of the exclusive peaceful use of the NES – including a legal basis for verification activities implemented by the IAEA. It should be noted that the NES has a gap in sustainability as defined in the INPRO Methodology if a given State has a CSA in force [6] without an AP [7]; in that case, the IAEA is not able to provide credible assurance of the absence of undeclared nuclear material and activities in the State as a whole.

The third question is associated with UR3, the facilitation of "easy detection" of diversion of nuclear material and/or misuse of nuclear facilities. It is implied that implementation of safeguards should avoid unnecessary impacts on operations and respect the principle of acceptable cost efficiency. Safeguards-by-design (SBD) principles are considered to be good practice.

Following the BP finally the assessor is asked to examine the coverage of the NES and each plausible diversion path by multiple intrinsic features and extrinsic measures, suitable to reduce the attractiveness of such path**.**

4. Testing "Safeguardability" by a NESA Assessor

Safeguardability can be described as a property of a nuclear system that is based on design features and operational modalities that facilitate effective and efficient safeguards implementation. In this context it is understood by the IAEA Department of Safeguards "*that through careful planning safeguards systems and processes could be implemented that could increase the capability of safeguards organizations to detect the diversion of nuclear material and the misuse of a facility more effectively and efficiently, could be less intrusive to facility operators, and potentially could result in a lower total cost to the stakeholders"* [9]

The PROSA approach assesses the safeguardability of a NES using a layered "Evaluation Questionnaire". The assessment of UR3 answers the questions: 1) "does design and operation of the NES facilitate the implementation of effective IAEA safeguards", and 2) "can safeguards objectives be met efficiently". In safeguards terminology, effectiveness addresses verification of the completeness and correctness of States' declarations, while efficiency considers the optimization of cost and resource burdens of implementation. In terms of safeguards, this means that effective safeguards can be implemented with a minimum acceptable (or practicable) expenditure of time, resources (including money) and effort.

The assessment is largely focused on facilities. The depth of analysis required leading to the conclusion that (IAEA) safeguards is/can be implemented effectively and efficiently depends on the status of the nuclear programme (e.g. whether the State is embarking on nuclear power or has an existing NES) and on the technology selected (e.g. proven, evolutionary or innovative technology, material category, item or bulk handling facilities, etc.).

In the case of proven technology, listing one or more technically comparable cases of implementation under comparable safeguards regime circumstances can make a positive finding. For example, if a reactor is to be installed and its site specific design requirements do not impact the safeguards approach previously implemented elsewhere on the same reactor design (under comparable safeguards regime conditions), then a preliminary finding can be made that effective safeguards can be implemented and the supporting evidence is the particulars of the comparable installation with previously implemented safeguards. This is the simplest case of a comparative assessment of safeguards effectiveness. For a country embarking on nuclear power such a test might be sufficient, and the evidence can be provided by the vendor.

Evolutionary technology requires by the designer and safeguards experts first an analysis of the impact of design differences on diversion paths: alteration of existing or even additional diversion paths. Secondly, it requires an analysis of the impact of design differences on safeguards implementation: on Physical Inventory Verification (PIV), on Interim Inventory Verification (IIV), on Inventory Change Verification, on Design Information Verification (DIV), and on the application of Containment/Surveillance (C/S) measures. To perform such kind of comparative assessment "Facility Safeguardability Assessment Screening Questions" [10, 11] have been proposed.

In the case of new construction, PROSA recommends the Safeguards-by-Design (SBD) concept, an approach whereby international safeguards requirements and objectives are fully integrated into the design process of a nuclear facility, from initial planning through design, construction, operation and decommissioning [12]. Fully-integrated means, *inter alia,* that safeguards requirements are included in the formal facility design optimization process. This includes design and construction issues such as locations of potential measurement stations and tamper indicating seals, cabling pre-installation, containment considerations, penetrations, as well as camera views and lighting.

Once a determination is made that the installation under consideration in an NES is based on evolutionary or innovative technologies, a preliminary determination can be made regarding the technical readiness of IAEA certified instrumentation [13] to support safeguards implementation on the proposed installation.

Novel facility technology or processes require a detailed analysis starting in the conceptual design phase with a facility level coarse diversion path (diversion strategy) analysis in the same tenor as the SBD-process (from the initial planning through the design, construction, operation and decommissioning). This analysis entails a consideration of (hypothetical) schemes which a State could use to divert or to misuse nuclear material subject to IAEA safeguards. Each diversion strategy may include one or more concealment methods. The purpose of a coarse diversion path analysis at this stage is to determine whether appropriate safeguards measures exist to provide sufficient detection capabilities. For the optimization of the design and operation of a facility a detailed diversion path analysis can be useful

PROSA proposes two complementary approaches for the analysis of the installation/facility to test the safeguardability. One approach is the comparative assessment considering the safeguards relevant similarities between existing and novel technology, which provides insights for the SBD-process. A second approach is to use a safeguardability checklist "to determine that the system's design facilitates all the activities related to the implementation of nuclear safeguards by the IAEA" [14].

Table 1 and 2 summarize the Evaluation Questionnaire, illustrative tests [14] and screening questions [10, 11] for the safeguardability of a NES.

Table 1: Typical Evaluation Questionnaire

Evaluation Parameter	Question	Finding	
EP3.1.1 The accounting system, required by the SSAC and implemented by the operator provides accurate and complete information on nuclear materials, forms, amounts, flows, locations, transfers and identification of inventory changes	Procedures for Inventory Taking have been established equal to good practice [15]	yes	no
	Nuclear material (NM) inventories are properly tagged and identifiable	yes	no
	International Standards of Accounting are met [16]	yes	no
	International Target Values are met for DA and NDA [16]	yes	no

Table 2: Illustrative Tests and Screening Questions for the assessment of the safeguardability of a NES

Generic Safeguardability Test [14]			**Comparative Approach** [10,11]	
EP3.1.1	Procedures for Inventory Taking (PIT) have been established equal to best practice [15]		**EP3.1.1**	Procedures for Inventory Taking (PIT) have been established equal to best practice [15]
Test	The foreseen PIT procedures can take into account all relevant needs		**Question**	Does this design lessen the efficiency of PIT by the operator or the effectiveness of PIV by the IAEA
	The NMAC system has follow-up / tracking functions that provide timely information about the locations and characteristics of all NM in the system			Does this design impair the ability of the operator to produce timely and accurate interim inventory declarations
	International Standards of Accounting [16] are met			International Standards of Accounting [16] are met
Test	It is possible to carry out measurement activities with accurate and precise quantification of the material that will be referred to in accounting declarations		**Question**	Does the design/process employ nuclear material types, categories, or forms that are more difficult to measure accurately at IKMP? If so, can the plant accountancy measurement system meet International Target Values (ITV) for the PIT
	The amount of hidden inventory is as low as reasonably achievable			

Besides the effectiveness of safeguards implementation, the other aspect of safeguardability is efficiency. For an evaluation of efficiency, PROSA proposes a comparative approach. Absolute comparison of cost values does not provide a useful result because each cost assessment is State-, facility- and activitydependent. This is especially true for the overall facility size (throughput), for labor costs and possible losses in production on the operator's part, as well as for the travel costs for IAEA inspectors and technicians. In addition, the number of inspectors required for verification depends on the safeguards agreements in force (the facility attachments in place) between the IAEA and the State (e.g., whether a type of "Partnership Approach" that shares the work and costs exists or not can have a significant influence).

For the owner/operator of a nuclear facility, "efficiency of safeguards implementation" means acceptable/minimal cost/burden both in construction capital investments and in operation. Relevant costs for the owner/operator of a nuclear facility, caused by the difficulties in implementation of IAEA safeguards, that go beyond normal construction and operating costs include (but may not be limited to):

- Back fitting of nuclear installations to meet safeguards requirements,
- Interference with normal operation,
    - Additional outages due to PIV/IIV
    - Restrictions in operation with impact on the operational capacity
- Need for additional facility-owned equipment enabling verification at PIV/IIV.

For safeguards authorities, "efficiency of safeguards implementation" refers to facility-specific, affordable costs in terms of manpower (inspection, analysis and technical support staff), safeguards equipment, and use of analytical laboratory facilities. Assessing the efficiency of the implementation of IAEA safeguards may require consultation with the IAEA Department of Safeguards (SG).

5. Case Study

To illustrate the proposed PROSA process, to demonstrate its usefulness, and to provide input to the revision of the INPRO manual in the area of proliferation resistance, a preliminary case study has been carried out by KAERI in Republic of Korea on a conceptual sodium-cooled fast reactor (SFR) metal fuel manufacturing facility (SFMF), representing novel technology in the conceptual design phase. This allows testing all elements of the proposed assessment process, from the early stage of design, and illustrates the interrelationship of the PR assessment to the safeguards-by-design process [17].

The SFMF in the case study has been defined to consist of the fuel rod fabrication module and fuel assembly module, but excludes the pyroprocessing module for simplicity. The feed material for SFMF is basically U/TRU/RE/Zr ingots produced from spent SFR fuel at the pyroprocessing module. TRU stands for transuranics and RE rare earth elements. The building with three main modules would also include the waste storage, maintenance cells (located above each main process module), laboratories and utilities, and was designed as a 3-floor building with a basement [18].

Safeguards implementation is assumed to be based on the accountancy system of the operator. Whether data from process control will be shared with the IAEA for safeguards purposes, or whether NMCA systems are to be duplicated, has to be subject to further analysis and negotiation with the IAEA in the course of the safeguards-by-design (SBD) process. Basic principles of NMCA and potential safeguards measures are that:

- The facility is designed for remote operation, no human access to process areas except for maintenance due to inert gas, radiation and high temperature safety issues,
- All SFR fuel materials to be measured and monitored in process,
- Extensive use of unattended weighing and NDA and surveillance systems to verify 100% of the SFR fuel material flows in the process,
- Extensive use of video surveillance to monitor and maintain the continuity of knowledge of SFR fuel materials (amounts and locations) is expected, including in the scrap recovery and product/waste storage areas,

- All NMCA/safeguards systems can be designed to accommodate automated facility operation, i.e. no need for the operator to shut down the process activities for interim verification,
- Additional equipment for each NDA instrument is foreseen, such as video cameras to confirm ID numbers of the object or independent load cells to confirm the gross weight of the container being assayed,
- All unattended NDA and surveillance systems to be suitable for "remote monitoring."

A coarse diversion path analysis has been carried out which does not claim to be complete, but which is sufficiently detailed for demonstrating the assessment process. By applying the PROSA safeguardability questionnaire (UR3) to each diversion path so far identified it was possible to gain an appreciation of where gaps exist thereby suggesting R&D opportunities to improve the long term sustainability of the NES. Critical areas identified include:

- Procedures for destructive assay (DA) for the verification by the IAEA are not defined
- Target values for non-destructive assay (NDA) for this type of nuclear material are also not defined
- Need to finish demonstrations of NDA measurements on novel material types and material flows

Recommendations for improvements / R&D have been associated with NDA equipment (like ASNC (Advanced Safeguards Neutron Coincidence Counter) or PNAR (Passive Neutron Albedo Reactivity) instruments, etc. with 2-5 % measurement uncertainty, under development at KAERI) that is still to be validated and approved for use by the IAEA, with surveillance systems to make sure that held-up material in the equipment module (i.e., heel) cannot be removed from the process cell without detection by safeguards, and with discrimination capabilities between waste containers loaded with waste or with TRU fuel and heel/scrap.

6. Conclusion

The proposed PROSA assessment process is an improved approach to identify strengths and weaknesses of a system in the areas of proliferation resistance and safeguardability (UR3), which can help Member States to identify R&D gaps that need to be addressed in order to meet the expectations for sustainability of a nuclear energy system. The primary value of the assessment is to gain an appreciation of where gaps exist, thereby suggesting directions to pursue to improve long term sustainability of the NES.

While PROSA is narrow to a specific NES sustainability self-assessment, it is complementary to the promotion of the SBD concept by the IAEA Department of Safeguards [9, 12]. The PROSA self-assessment cannot replace the responsibility of the IAEA for the development of a safeguards approach for a specific facility; however, it provides useful information to national experts, designers and operators on how to address elements of safeguards in the basic design, and how to improve the safeguardability of the system.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual – Overview of the Methodology, IAEA-TECDOC-1575 Rev.1, IAEA, Vienna (November 2008).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual – Proliferation Resistance, Volume 5, IAEA-TECDOC-1575, IAEA, Vienna (2007).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, INPRO Collaborative Project: Proliferation Resistance: Acquisition/Diversion Pathway Analysis (PRADA), IAEA-TECDOC-1684, IAEA, Vienna (2012).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Proliferation Resistance Fundamentals for Future Nuclear Energy Systems, IAEA STR-332, Department of Safeguards, IAEA, Vienna (2002).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/140, IAEA, Vienna (1970).
[6] INTERNATIONAL ATOMIC ENERGY AGENCY, The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/153 (Corrected), IAEA, Vienna (1972).
[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (Corrected), IAEA, Vienna (1998)
[8] Eckhard Haas, Hong-Lae Chang, James K. Sprinkle, Jon R. Phillips, Yusuke Kuno, Outcome of the INPRO Collaborative Project "Proliferation Resistance and Safeguardability Assessment Tools (PROSA)," Proceedings of the 55th INMM Annual Meeting, Atlanta, Georgia, July 2014.
[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Facility Design and Plant Operation Features that Facilitate the Implementation of IAEA Safeguards, IAEA-STR 360, Department of Safeguards, Vienna (2009)
[10] U.S. DOE, Overview of the Facility Safeguardability Analysis (FSA) Process, PNNL-21698, August 2012
[11] US DEPARTMENT OF ENERGY, Trial Application of the Facility Safeguardability Assessment Process to the NuScale SMR Design, PNNL-22000 Rev.1, January 2013
[12] INTERNATIONAL ATOMIC ENERGY AGENCY, International Safeguards in Nuclear Facility Design and Construction, NE Series Document NP-T-2.8, Vienna (2012)
[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Safeguards Techniques and Equipment: 2011 Edition, International Nuclear Verification Series No. 1 (Rev. 2)
[14] UNIVERSITY OF BRISTOL Resisting Nuclear Proliferation Through Design, A System Approach To Nuclear Proliferation Resistance Assessment, Guido Renda, A dissertation submitted to the University of Bristol, December 2008
[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Material Accounting Handbook, IAEA Services Series No. 15, May 2008
[16] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safeguards Glossary 2001 Edition, International Nuclear Verification Series No.3, IAEA, Vienna (June 2002)
[17] Hong-Lae Chang, et al., A Case Study for the INPRO Collaborative Project "Proliferation Resistance and Safeguardability Assessment Tools (PROSA)", INMM, 55th Annual Meeting, Atlanta, Georgia, 2014
[18] Won Il Ko, et al., Preliminary conceptual design and cost estimation for SFR Fuel Manufacturing Facility (SFMF), Nuclear Engineering and Design 277 (2014), 225-233.